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Continuum EoS for QCD with $N_f = 2+1$ flavors

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(Wuppertal-Budapest collaboration)

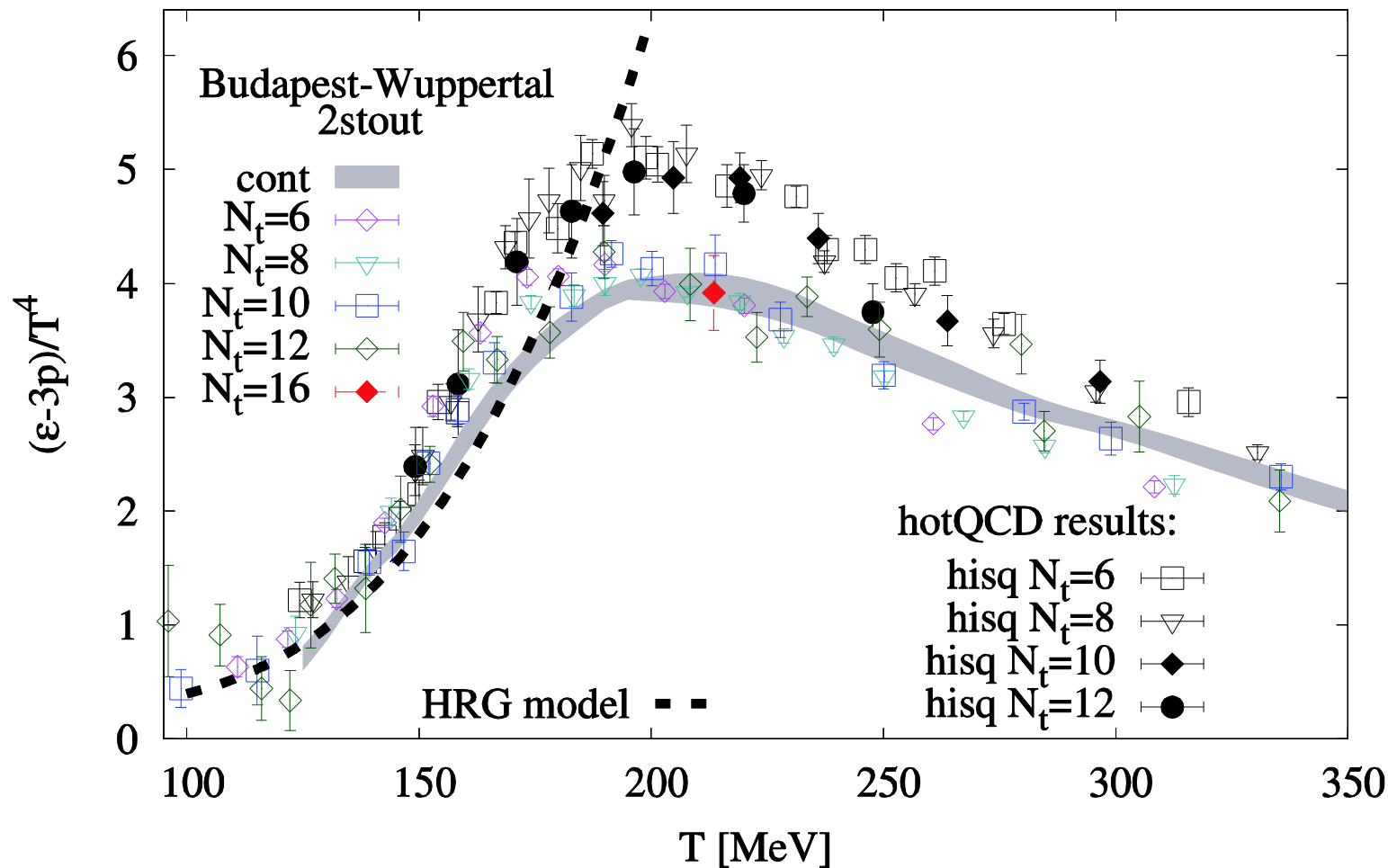
28.11.2012 | Stefan Krieg



Outline

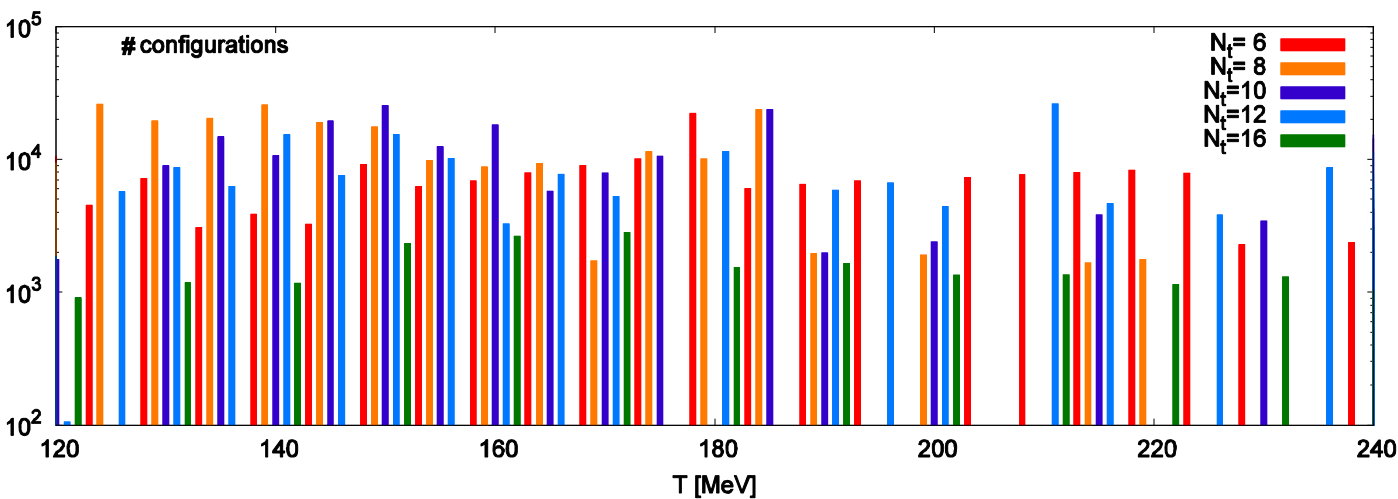
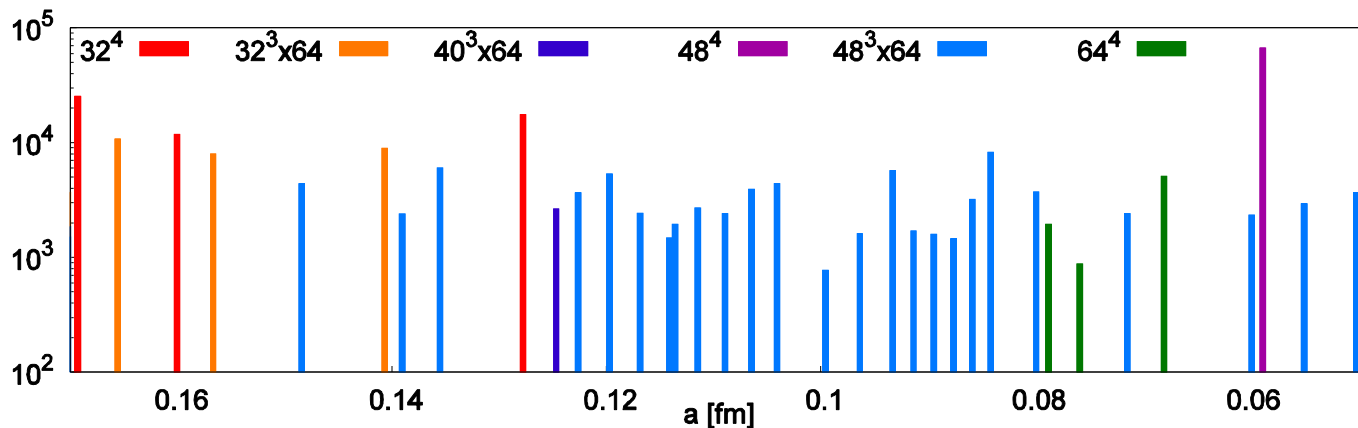
- Motivation
- Simulation
 - Ensembles/statistics
 - Scale setting (LCP)
 - $T/2$ subtraction
 - Systematics: finite vol., lattice spacing, histogram method
- Results
 - Trace Anomaly, comparison with literature
 - Pressure, entropy, energy density, speed of sound
- Conclusions

Motivation: status 2012

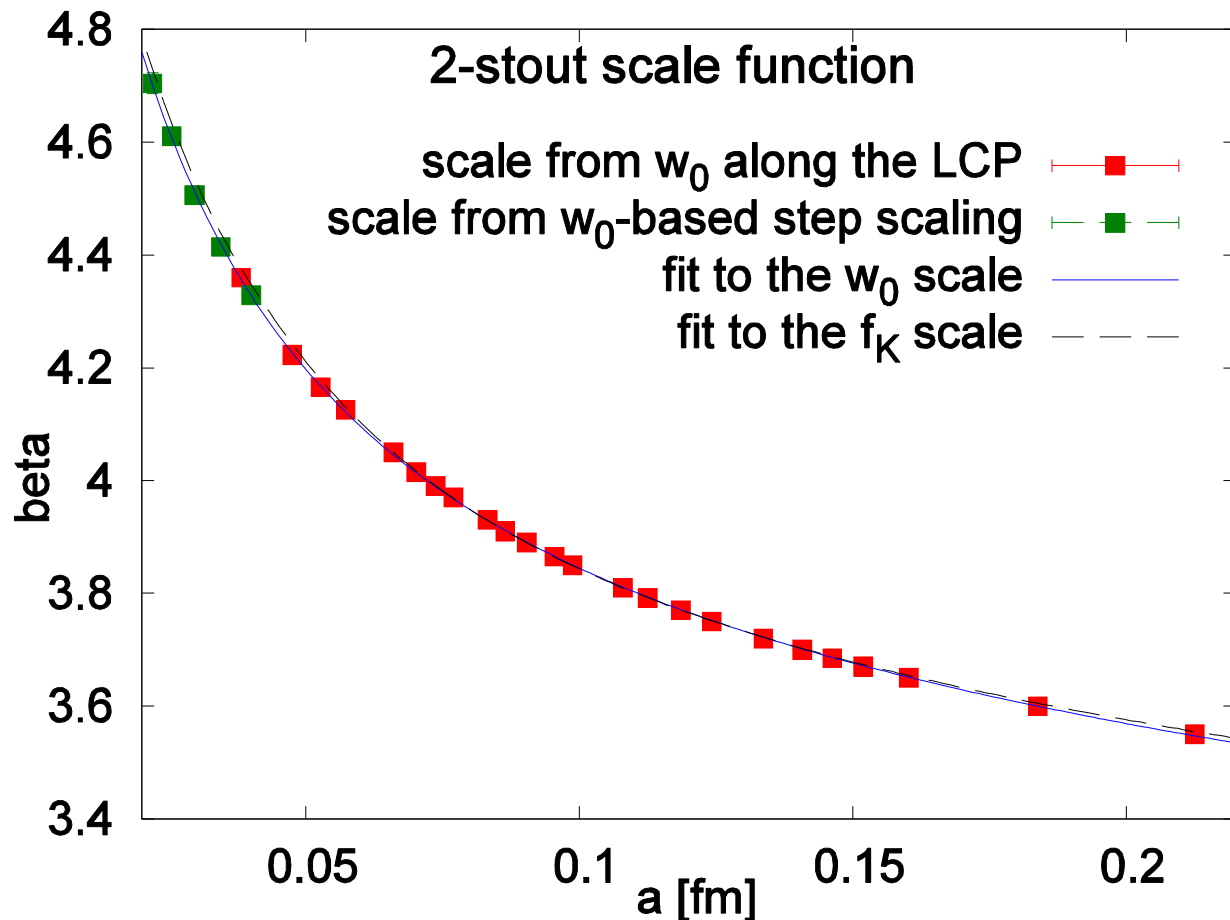


Simulation: ensembles/statistics

trajectories



Simulation: scale setting



w_0 : JHEP **1209** 010

Aim: estimate error of scale setting procedure

- original LCP
- step-scaling procedure like in 2010, w_0 based observable
- deviations on the 2% level
- Included in analysis

Simulation: T/2 subtraction

- Reaching large temperatures requires small lattice spacings
- Algorithmically T=0 runs have difficulties to reach $a < 0.05$ fm (frozen topology, diverging autocorrelation times).
- Solution: T/2 subtraction:

$$I_{\text{sub}}(T) = (I(T) - I(T/2))_{\beta(a_0)} + (I(T/2) - I('T=0'))_{\beta(2a_0)}$$

- Requires new simulations, however these are still in the high-temperature phase ($N_t=8 \rightarrow N_t=16, \dots$)

Systematics

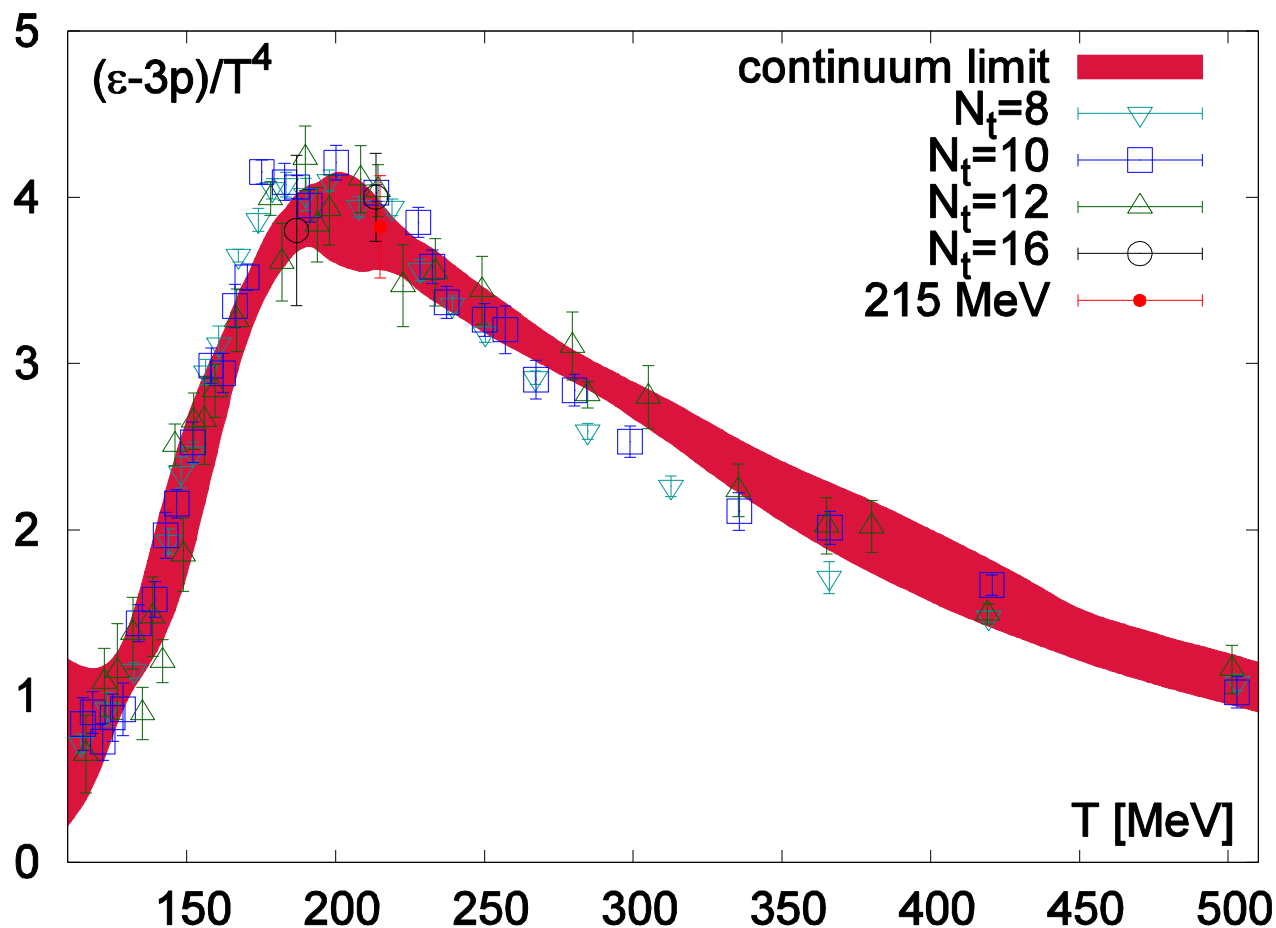
- Finite volume effects
 - Studied explicitly in 2010 (see also Lattice 2011):
 - no effects (larger than statistical errors) seen.
 - This study includes larger volumes

→ Finite volume effects will be negligible compared to other systematic uncertainties
- Scale setting and lattice spacing artifacts
 - We vary the range of lattice spacings in our fits:
 - $N_t=6$ is included or left out
 - We use different scale settings
 - We include $O(a^4)$ in our fit procedure

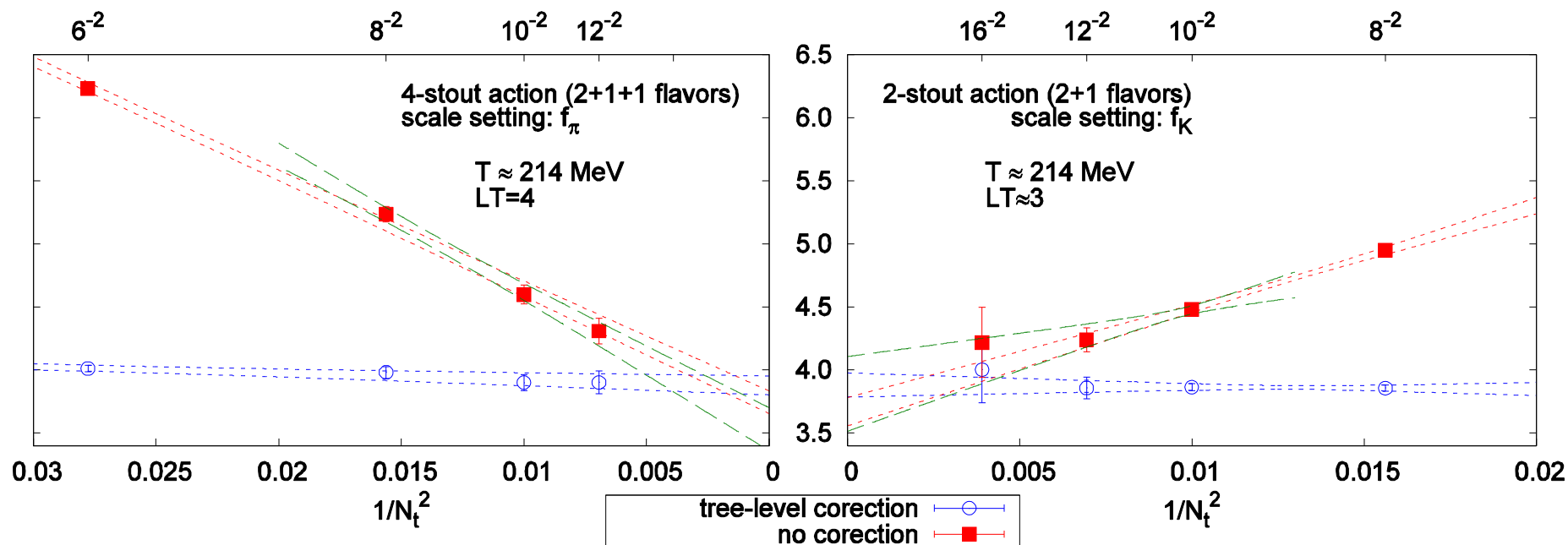
Simulation: systematics, histogram method

- vacuum fits
 - 7 different fit models (incl. direct subtr. w. interp.)
 - continuum extrapolation
 - Vary node points (8 different sets)
 - Include or leave out leave $N_t=6$
 - With or without improvement factors
 - We use two different scale settings (f_k vs. w_0)
 - Fit includes a^2 or a^2 and a^4 terms
- This results in $7 \times 8 \times 2 \times 2 \times 2 \times 2 = 896$ different fits
- Weighting: we consider AICc, Q, or unweighted histograms

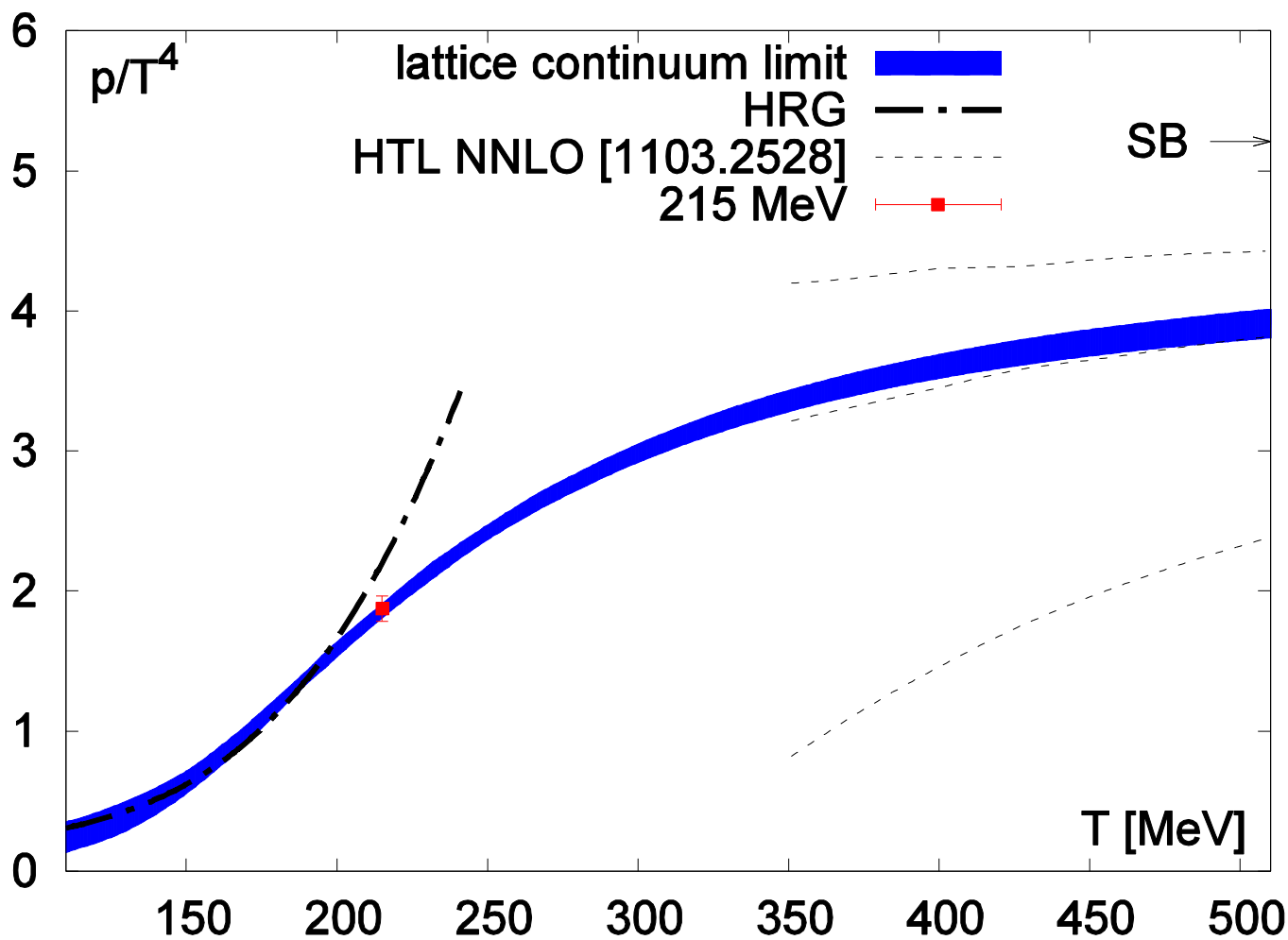
Results: trace anomaly



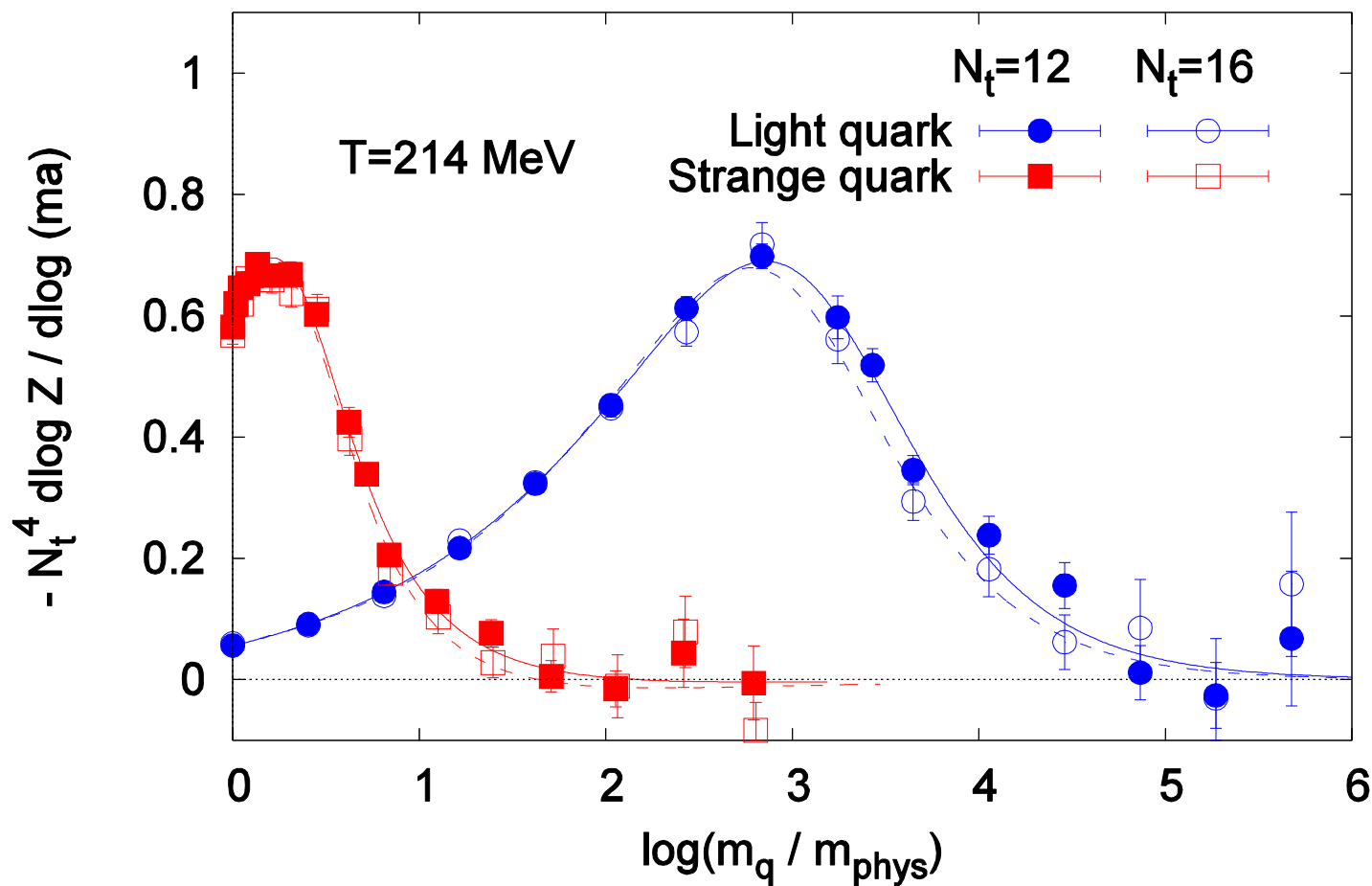
Results: trace anomaly @ 215 MeV



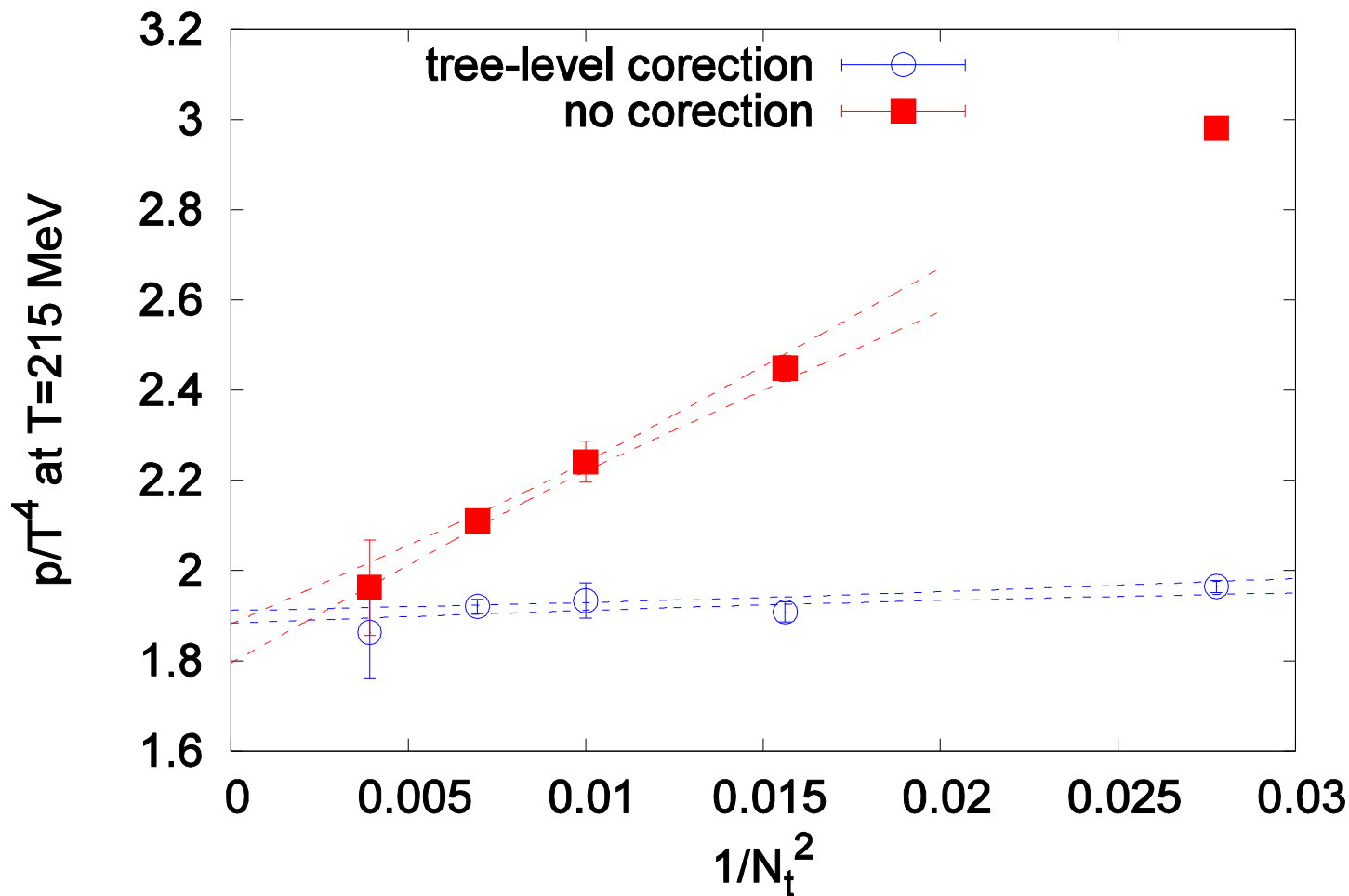
Results: pressure



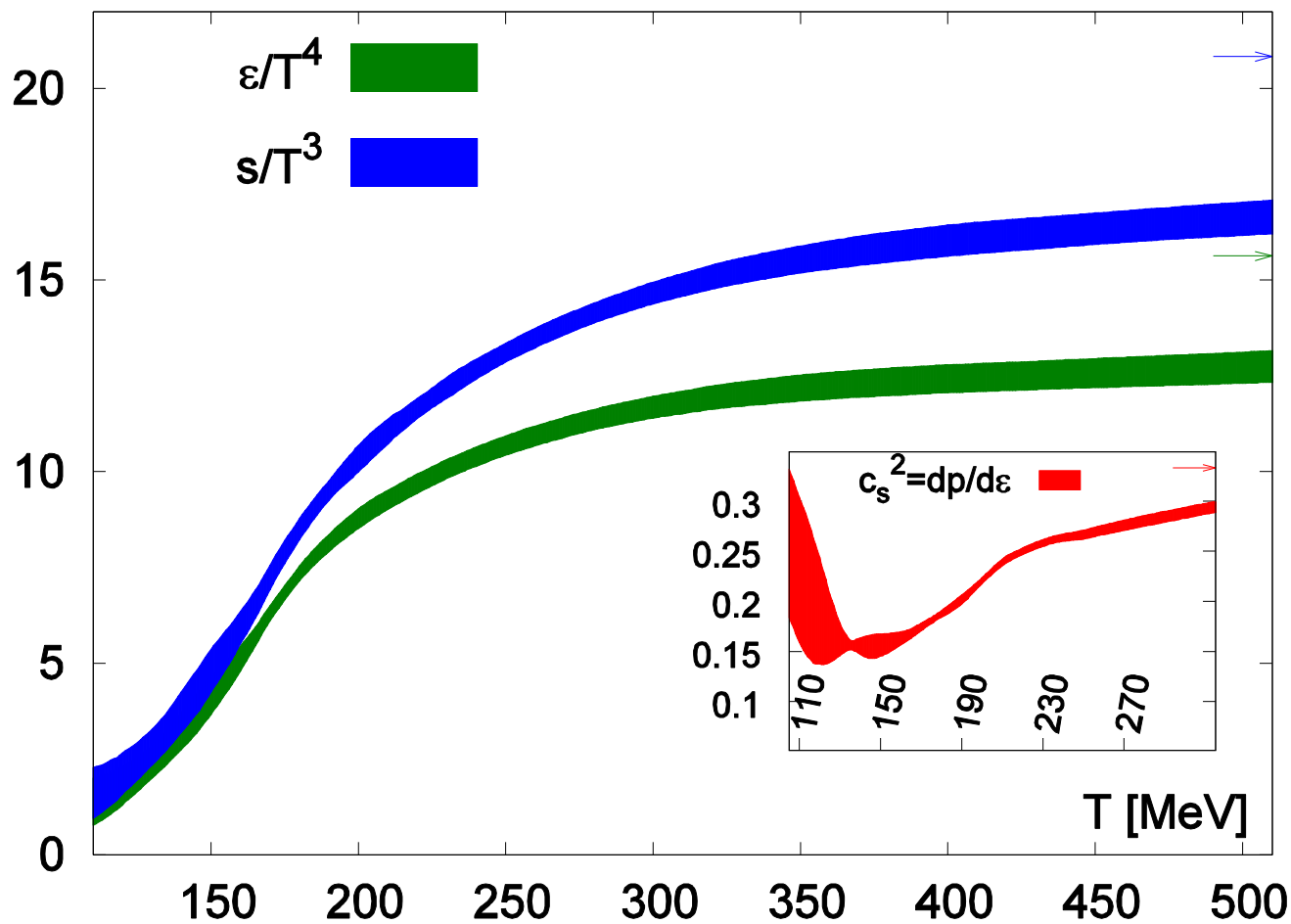
Results: pressure @ 215 MeV



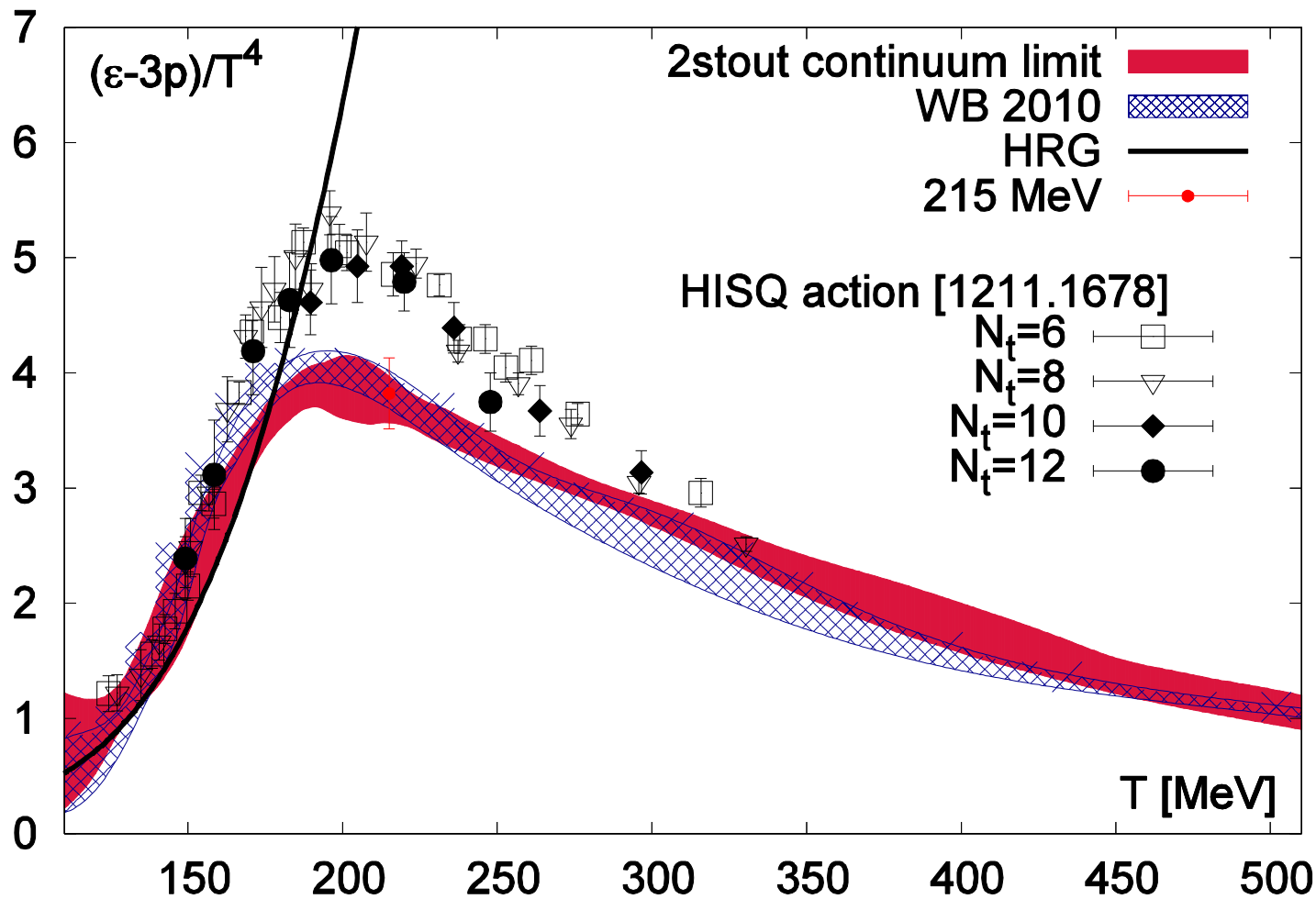
Results: pressure @ 215 MeV



Results: entropy et al.



Results: trace anomaly



Conclusions

- We have performed a continuum extrapolation of the EoS for $N_f=2+1$ QCD
- We carefully studied and included systematic uncertainties
- Within our error the discrepancy to the hotQCD/HISQ results remains
- Final conclusion requires continuum extrapolation of HISQ data combined with a study of systematic uncertainties.
- In any case above $T \approx 300$ MeV charm effects become important.



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Thank You for Your attention!

Simulation: ensembles/statistics

- Vacuum ($T=0$) runs:
 - Renormalization (& w_0 scale setting):
 - Volumes: 32^4 , 48^4 , 64^4
 - #traj.: $O(10^4)$ for 32^4
 $O(10^5)$ for 48^4
 $O(10^3)$ for 64^4
 - Scale setting (f_k):
 - Volumes: $32^3 \times 64$, $40^3 \times 64$, $48^3 \times 64$
 - #traj.: $O(10^4)$ for $32^3 \times 64$,
 $O(10^3)$ for $40^3 \times 64$ and $48^3 \times 64$

Simulation: ensembles/statistics

- Used available ensembles (see e.g. 1305.5161)
- Added ensembles:
 - $32^3 \times 6$, $32^3 \times 8$, with $13-50 \times 10^3$ trajectories
- Use sufficiently large volumes only
 - $L > 2$ fm for all T
 - $L > 5.3$ (12); 4.2 (10); 5.2 (8) @ 150 MeV
 - $48^3 \times 8$
 - $64^3 \times 10$
 - $64^3 \times 12$
- Additional $48^3 \times 16$, $64^3 \times 20$, $64^3 \times 24$ ensembles (T/2 subtraction, 215 MeV point)

Results: entropy @ 215 MeV

